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SHOCK INDUCED REACTION IN EXPLOSIVES AND PROPELLANTS

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March 1972

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TECHNICAL REPORT No. 103

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Shock Induced Reaction in Explosives and Propellants

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SUMMARY

Two propellants (a cast double-base and an extruded double-base) and two explosives (a 60/40 RDX/TNT mixture + 1% beeswax and nitromethane) were subjected to shocks of known amplitude. The shock producing system used was essentially that of the NOL Standard Gap Test. Threshold pressures for both burning and detonation were obtained. This technique (used originally by Jacobs and Liddiard) has been extended to provide unreacted Hugoniot data.

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Reference: WAC/220/01

1 INTRODUCTION

In accident circumstances probably the most frequently encountered stimuli for the initiation of explosive materials is by impact or shock.[1] Considerable work has been done on the initiation of detonation by shock but much less work has been done on the initiation of sub-detonation reactions. Remembering that many sub-detonation reactions themselves can be hazardous (they can also build into detonation) there is a real need for research into this area.

An experimental programme on the initiation of reaction in explosives by shocks of moderate amplitude was carried out by Jacobs and Liddiard[2] at the Naval Ordnance Laboratories (NOL), USA. In this work the threshold pressures both for burning and for detonation of a series of explosives were determined. Here the time for the shock pressure to decay by 50% of its peak value was estimated to be about 1 microsecond. Using incident pressures of longer duration on the same explosives, Liddiard later showed the threshold pressures for burning of these explosives to be much lower.[3]

This report is concerned with an experimental study of the initiation of reaction in explosives and propellants by shocks of moderate amplitude. As a preliminary this work will rank the explosives and propellants considered into an order of their resistance to shock (sensitivity). Future work will consider the effect of longer duration pulses on sensitivity.

2 EXPERIMENTAL

2 1 General

The experimental procedure used here was essentially that used by Jacobs and Liddiard.[2] The modified gap test used throughout this work was based on the donor-gap system of the NOL Standard Gap Test.[4] For that test the peak pressure in the gap of PMMA (polymethylmethacrylate), along the axis, has been calibrated as a function of gap length.[5] The shocks generated in an acceptor by this system are neither plane nor of uniform amplitude, either radially or axially. However, it has been established that the measured peak pressure in this system closely approximates that of more precise plane-wave systems.[6] Using a framing camera the motion of the free surface of the acceptor is observed. Any reaction within the acceptor causes the surface to move with a much greater axial velocity than anticipated (for unreacted acceptor). In addition, when the incident pressure is great enough to cause burning, a dark cloud of smoke is seen to emerge from the sample. At greater incident shock pressures transition to detonation is observed. This is characterised by a luminous zone of shocked air which moves axially above the escaping products.

2 2 Procedure

The test arrangement used in each experiment is shown in Figure 1. Two charge set-ups were tested simultaneously to conserve light sources. An end-on view of the acceptors was provided by a mirror at 45° to the camera viewing direction. Lighting was provided by argon flash bombs. The 51 mm diameter, 51 mm long, tetryl donor charges were pressed to a density of 1.5 g/cm³. EBW detonators, wired in series, were fired from a Beckman and Whitley 189 framing camera (4 μF capacitor charged to 6 kV). The PMMA (Perspex) gaps were machined to length from 51 mm diameter rod. The 13 mm thick plywood baffle prevented any gaseous detonation products (donor) from obscuring the view of the camera. The air-driven turbine in the B and W camera was run at speeds in the range 1000 - 5000 rev/s (ie ≈ $\frac{1}{4}$ to $1\frac{1}{4}$ million frames/s). These were chosen to give optimum results.

The explosive samples used (diameters 51 mm) were held to a density tolerance of ± 0.003 g/cm³ in all cases - the cast double-base propellant, ATN/D28/47, and the extruded double-base propellant, PU, had densities of 1.623 and 1.578 g/cm³ respectively. The RDX/TNT explosive had the composition RDX 59.5% (Spec No CS 1070F), TNT 39.5% (Spec No CS 5023), and Beeswax GS 1.0% (Spec No CS 2177). This pressure cast explosive had a density of 1.716 g/cm³. 51 mm diameter samples of nitromethane were held on the PMMA gap using PMMA collars of 51 mm internal diameter. These cells were filled with nitromethane until its meniscus top coincided with the top edge of the collar - this being the precise predetermined distance above the face of the PMMA gap. Samples of nitromethane were not degassed prior to use. A gas chromatographic analysis of the nitromethane showed the following composition: nitromethane 93.5%; nitroethane 2.0%; nitropropane 4.4%; and water 0.1%. The specific gravity was nominally 1.13 g/cm³.

2 3 Data Analysis

Using the experimental set-up shown in Figure 1, 12.70 mm thick × 50.8 mm diameter acceptors of the two propellants, the RDX/TNT mixture and nitromethane were subjected to shocks in the range 0 - 125 kb. Using the B and W camera the surface "blow-off" of the acceptors was photographed. From these records, values of U_a - "the axial velocity of the material 'blow-off' after 50 mm of travel" - were obtained. Graphs of U_a versus P_g (peak pressure in the PMMA gap incident on the acceptor surface) are shown in Figures 2 - 5. In these graphs the pressures P_b and P_d correspond to the threshold pressures for burning and detonation respectively. These pressures however are values of P_g. To find the corresponding values of P_e (P_{be} and P_{de}) "initial peak pressure transmitted to the explosive acceptor" (ie the true threshold pressures for burning, P_{be}, and detonation, P_{de}), we use the well known "impedance mismatch" method.[1] Mode of operation of this technique is shown in Figure 6. In these calculations the Hugoniot data (or pressure versus particle velocity relationship) for the RDX/TNT mixture was assumed to be very close to that published for Comp B3.[7,8] The calculations for the threshold pressures for burning and detonation of the RDX/TNT mixture are shown in Figure 7. Unreacted Hugoniot data for nitromethane are not in close agreement[9-11] and data for the two propellants is hitherto non-existent.

A new approach has been used to obtain data for these two propellants and for nitromethane. At incident shock pressures (P_g) below the threshold pressures for burning of these materials, the surface "blow-off" velocity crudely approximates the free-surface velocity (for the incident pressure P_g). Exact identity with this is lost due to the self attenuation of the shock pressure by the 12.7 mm thick acceptor. By measuring surface "blow-off" velocities of acceptors with thicknesses 3.18 mm, 6.35 mm and 9.53 mm (together with the 12.70 value) at one particular pressure P_g and by extrapolating back to zero thickness, a true value for the free surface velocity at P_g is obtained. To calculate the actual pressure transmitted to the acceptor (which causes this calculated free surface velocity) the impedance mismatch method is used as it were "in reverse" (see Figure 8). Here the particle velocity is taken as half the free surface velocity.[12,13] Figures 9, 10 and 11 show the free surface velocity calculations at a series of pressures. Figures 12, 13 and 14 show the Hugoniot results together with the calculations for the true threshold pressures for burning and for detonation respectively.

3 RESULTS AND DISCUSSION

Shock velocity (U) versus particle velocity (u) relationships for ATN/D28/47, PU and nitromethane respectively are given by the equations:

ATN/D28/47 $U = 1.28u + 1.88$

PU $U = 1.78u + 1.84$

Nitromethane $U = 1.96u + 1.56$

The threshold pressures for burning and detonation of the materials studied are shown in Table 1.

TABLE 1

Material	Threshold Pressure for Burning (kb)	Threshold Pressure for Detonation (kb)
ATN/D28/47	73	91
PU	80	110
RDX/TNT mixture	31	56
Nitromethane	-	104

The order of sensitivity of the two propellants is in agreement with that obtained from F1 gap tests - the 50% probability of detonation for ATN/D28/47 is at approximately 6 cards, and for PU approximately $4\frac{1}{2}$ cards. The sensitivity of the RDX/TNT mixture is lower than those for cast Comp B-3[2] and cast Cyclotol[2] (ie for cast Comp B-3, P_{be} = 14 kb and P_{de} = 36 kb; for cast 60/40 Cyclotol P_{be} = 15 kb and P_{de} = 47 kb). This lower sensitivity is almost certainly due to the presence of the beeswax.[14] Comparison of the data for the threshold pressure for detonation of nitromethane obtained with that of other workers is hindered by the probable difference in purity of the samples. Differences in unreacted Hugoniot data (Figure 15) may also be assigned to the differences in nitromethane samples. The particular nitromethane sample used here was part of an old consignment originally intended for use as a fuel. It is probably typical of the quality of nitromethane sample which might be handled or stored in bulk.

4 ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr R M H Wyatt and Dr K N Bascombe for their helpful advice throughout this work, and to Mr D C Ashton for his assistance with some of the experimental work.

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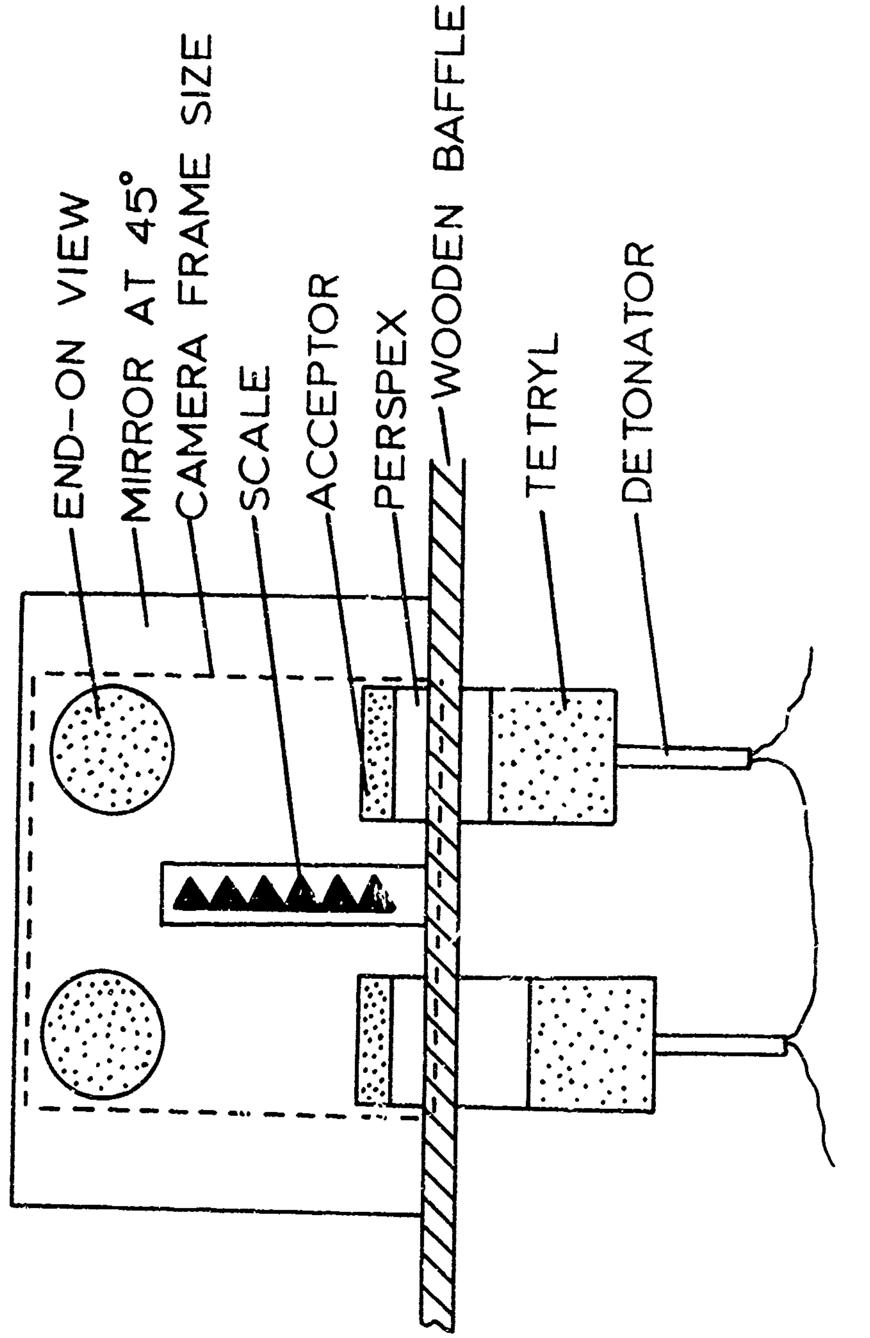

FIGURE 1 Modified NOL Gap Test Arrangement.

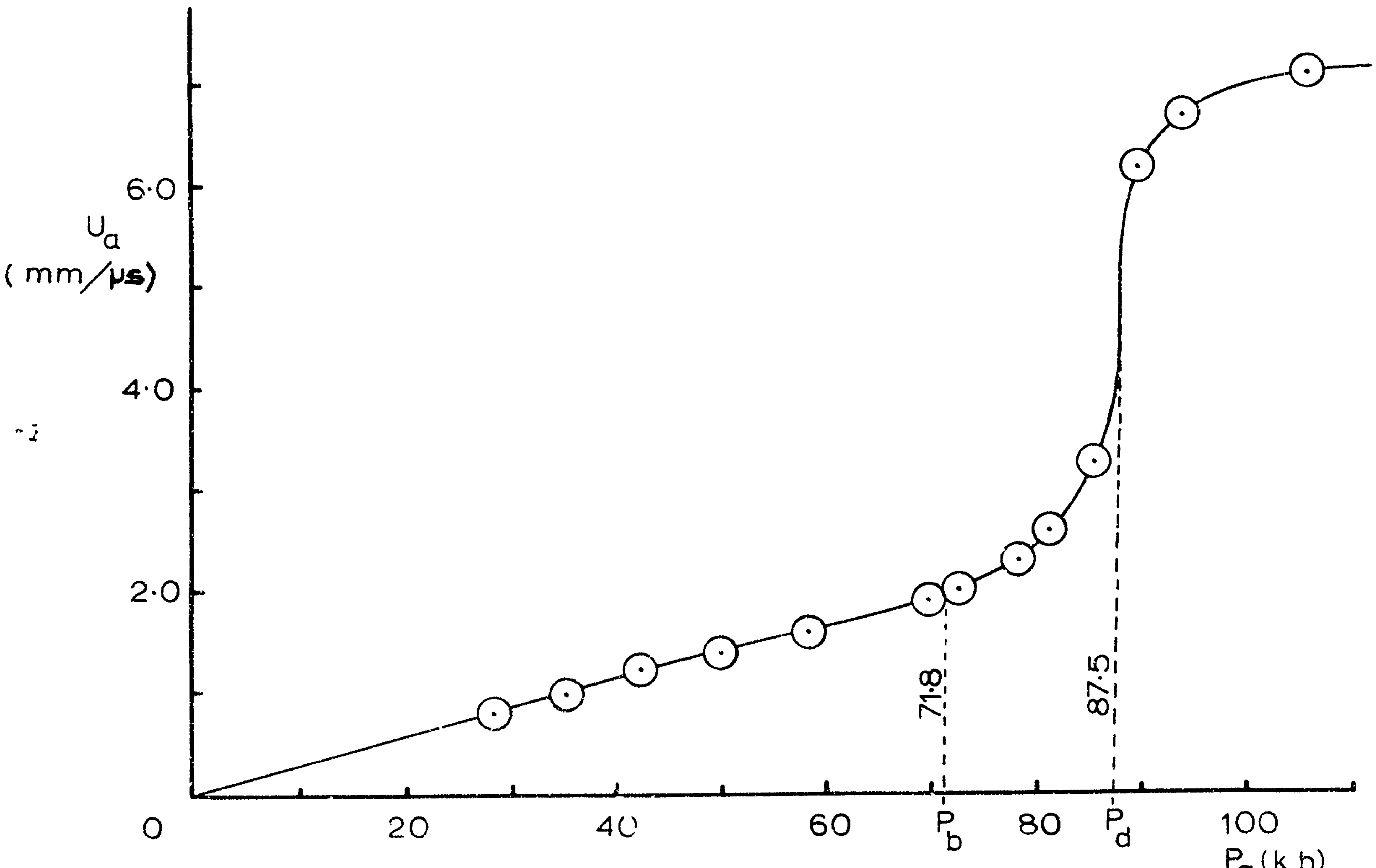

FIGURE 2 U_a versus P_g for ATN/D28/47.

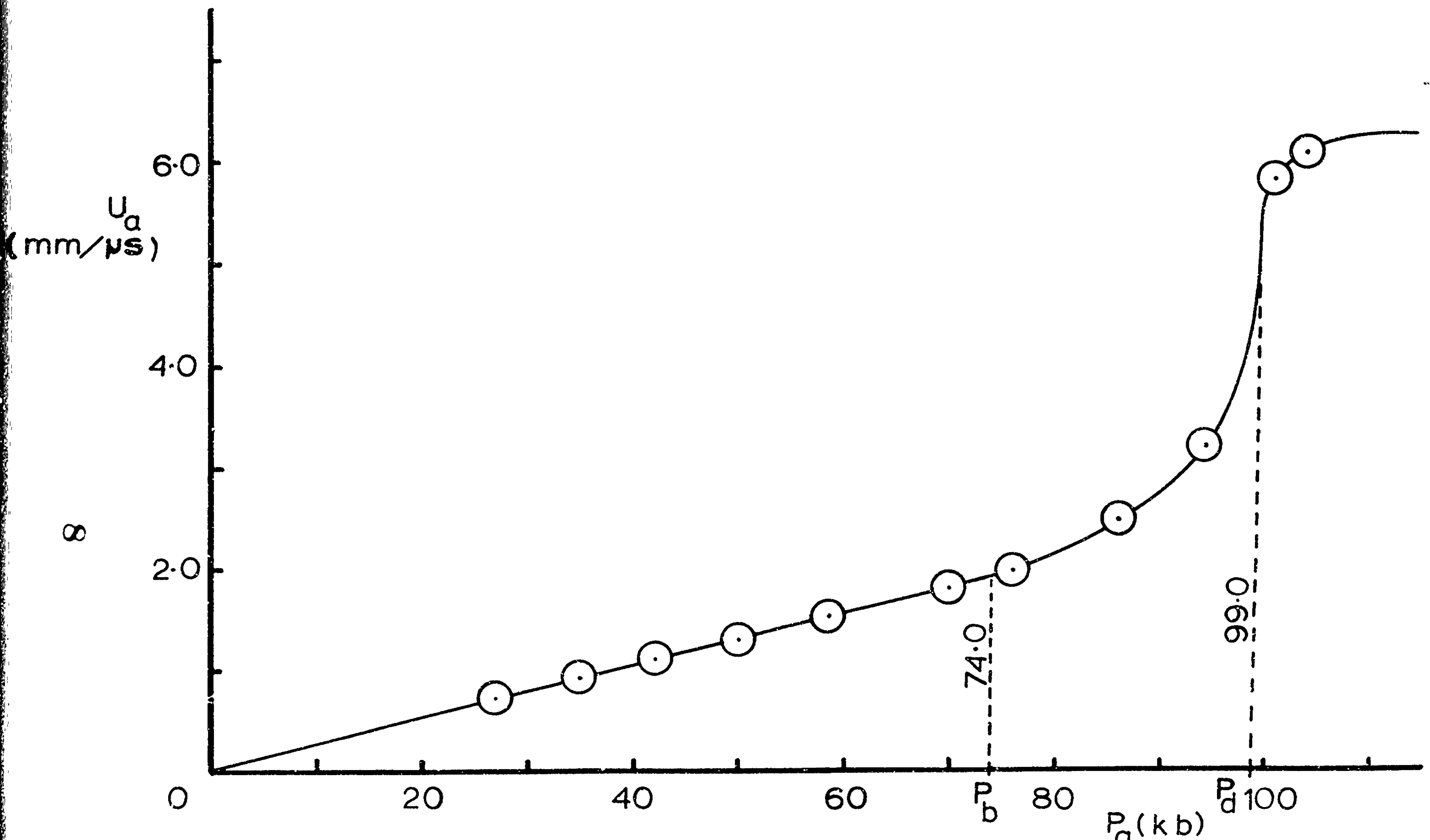

FIGURE 3 U_a versus P_g for PU

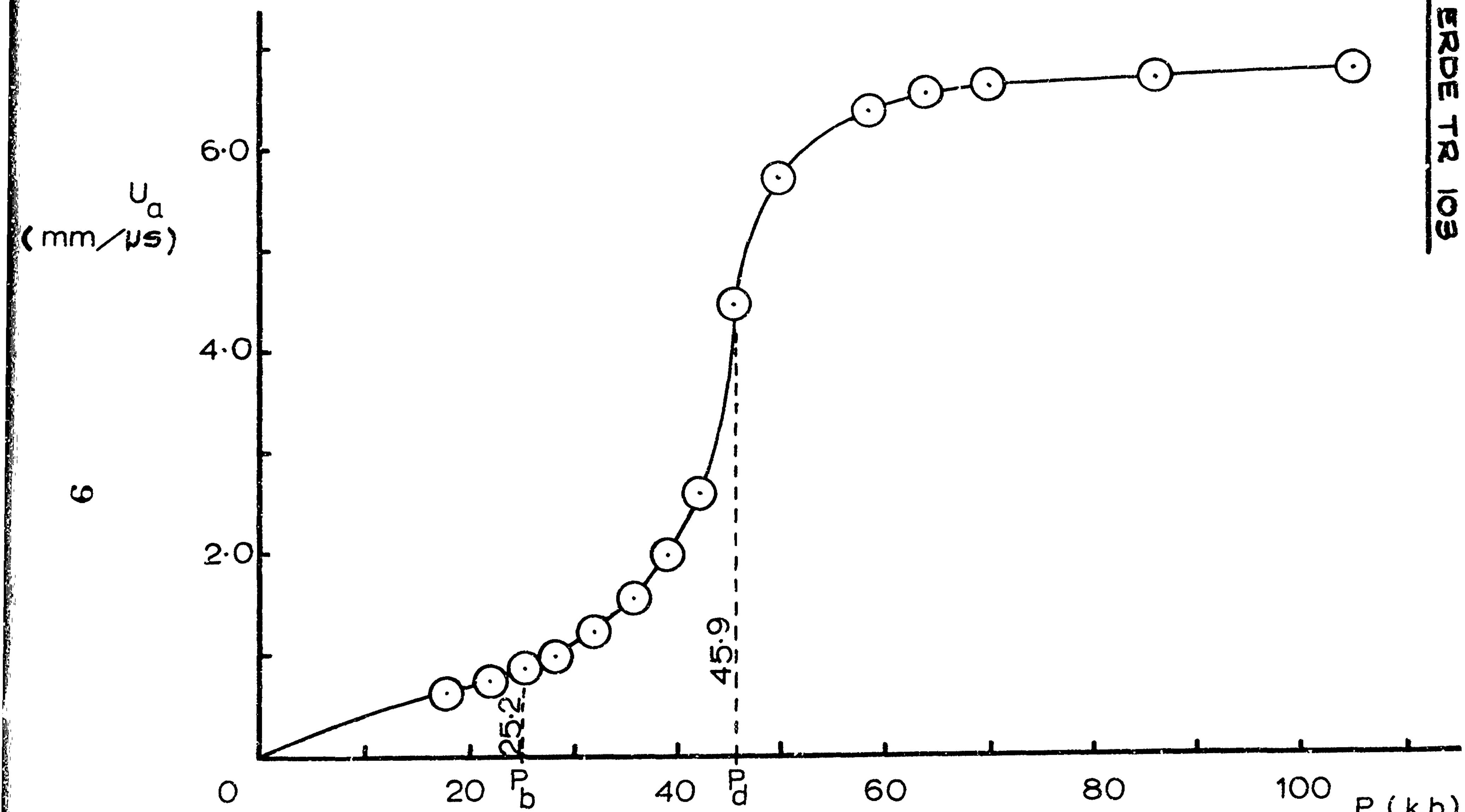

FIGURE 4 U_a versus P_g for RDX/TNT

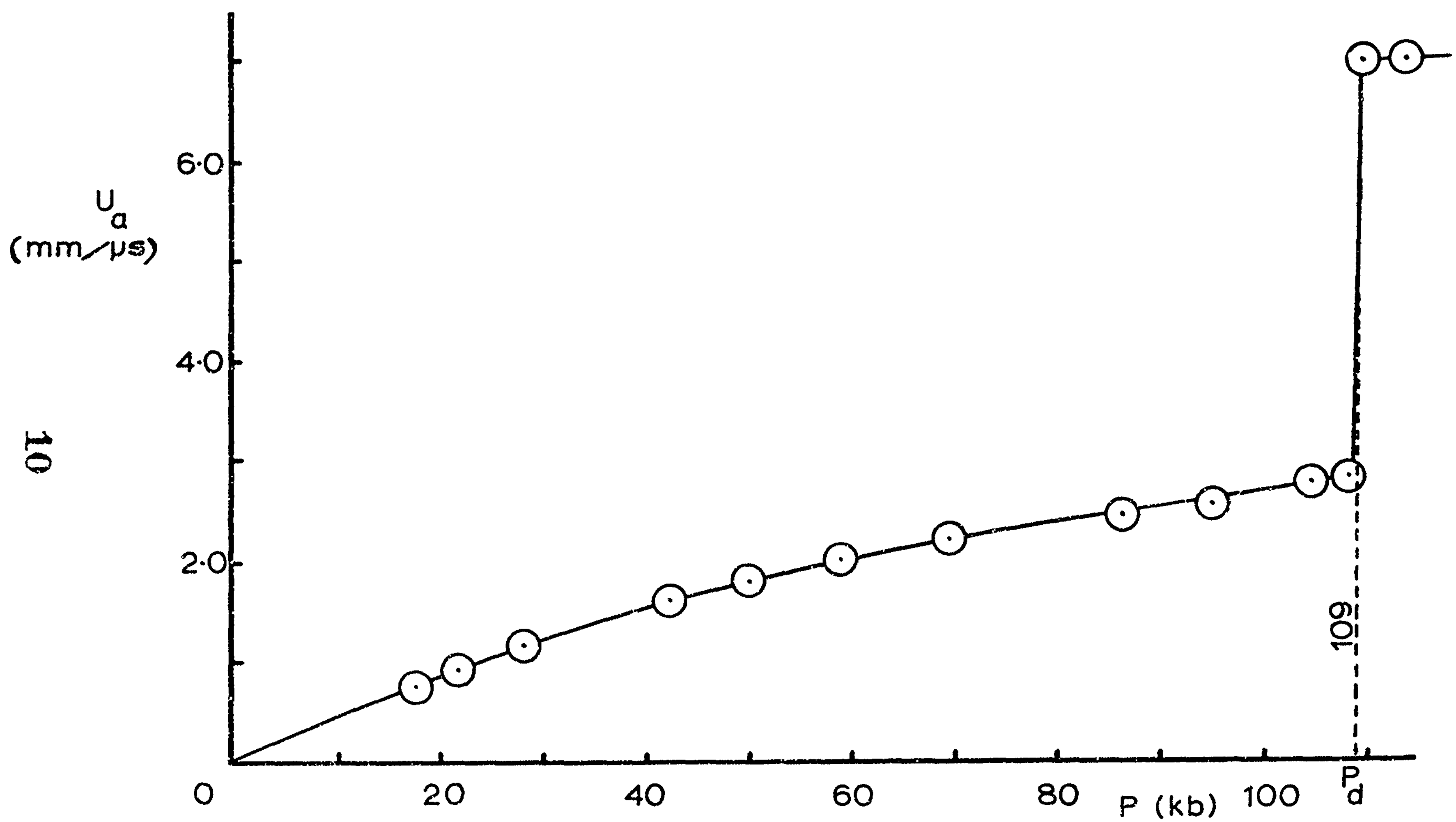

FIGURE 5 U_a versus P_g for Nitromethane.

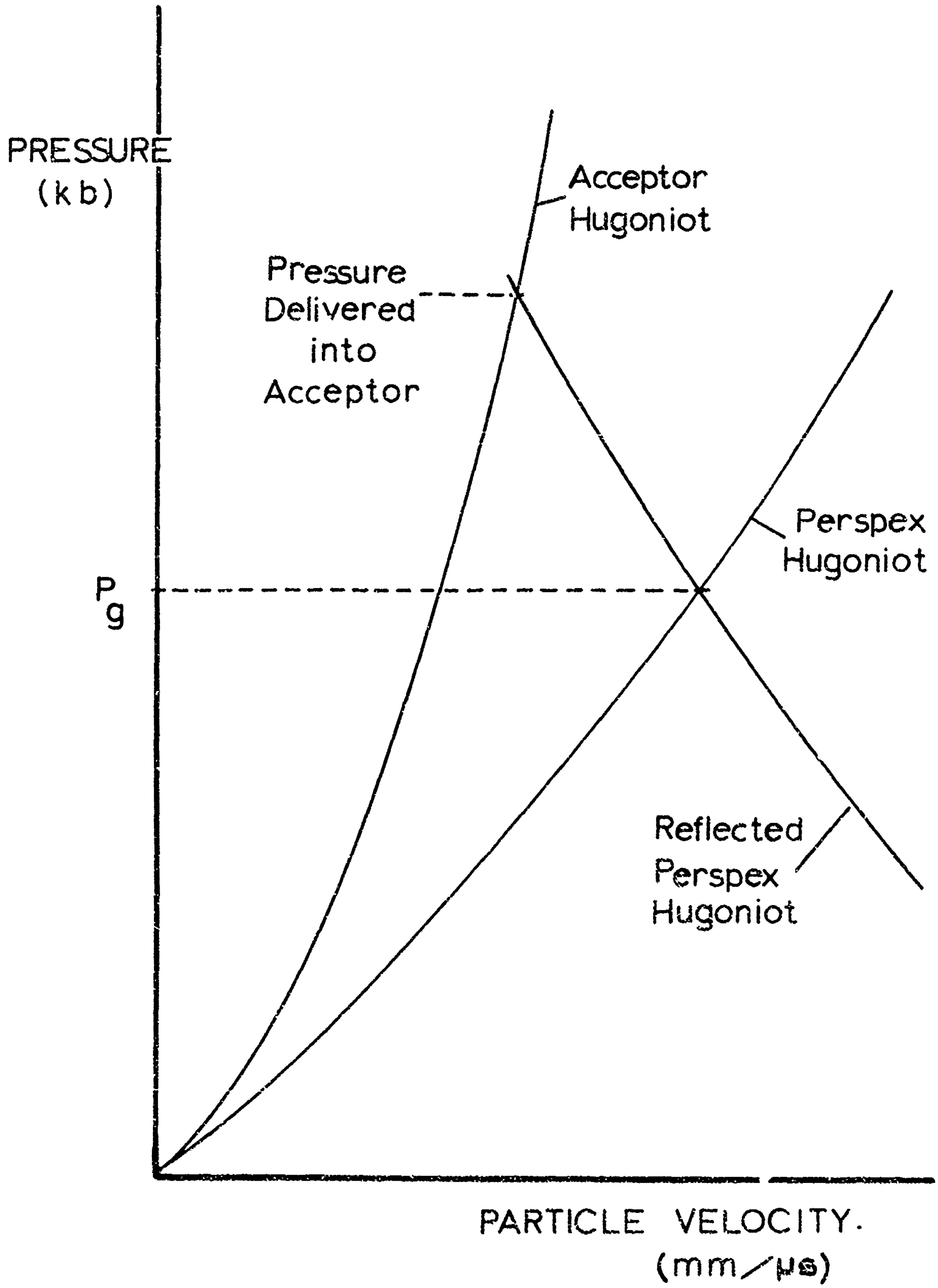

FIGURE 6 IMPEDANCE MISMATCH METHOD

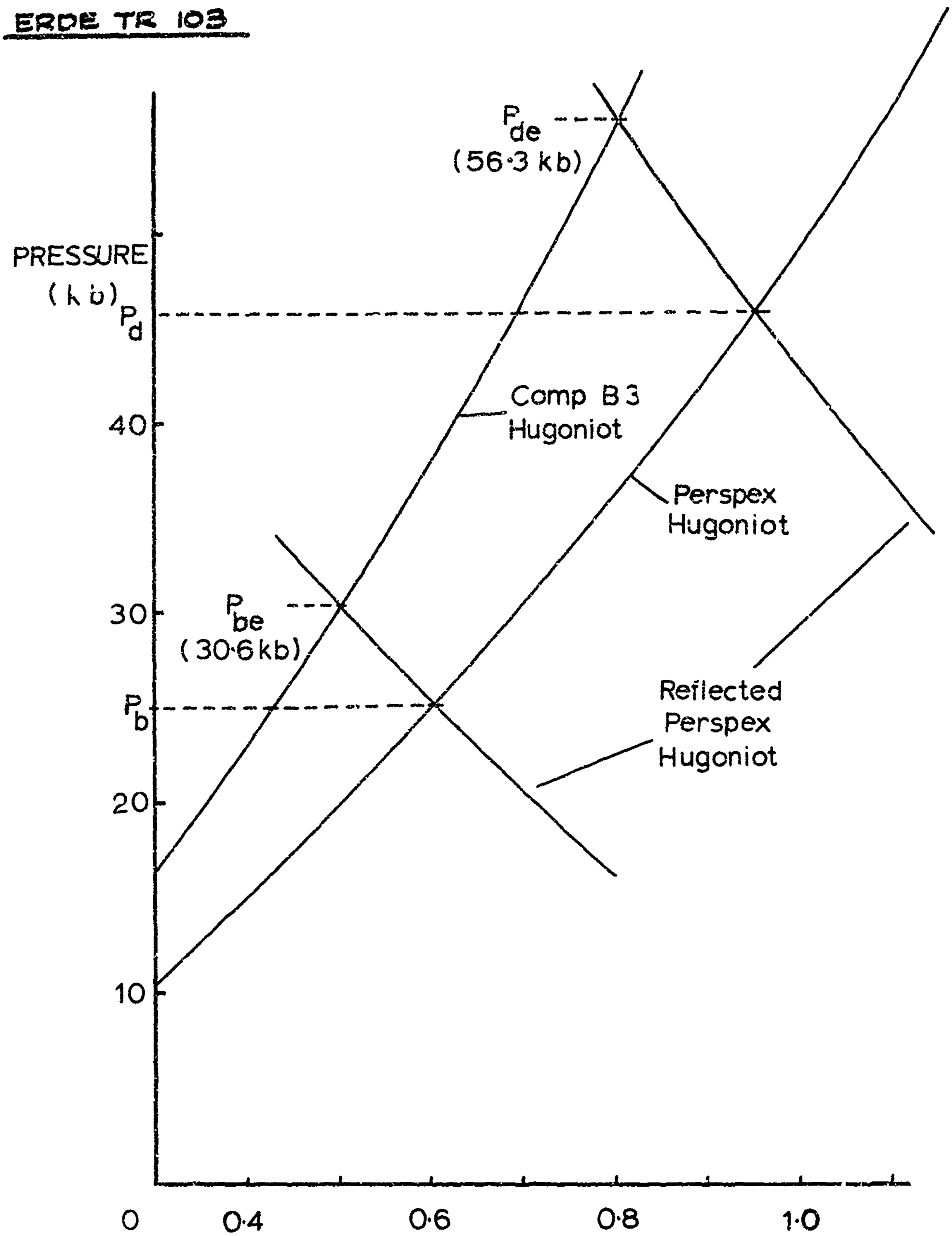

FIGURE 7 P_{be} and P_{de} Calculations RDX/TNT

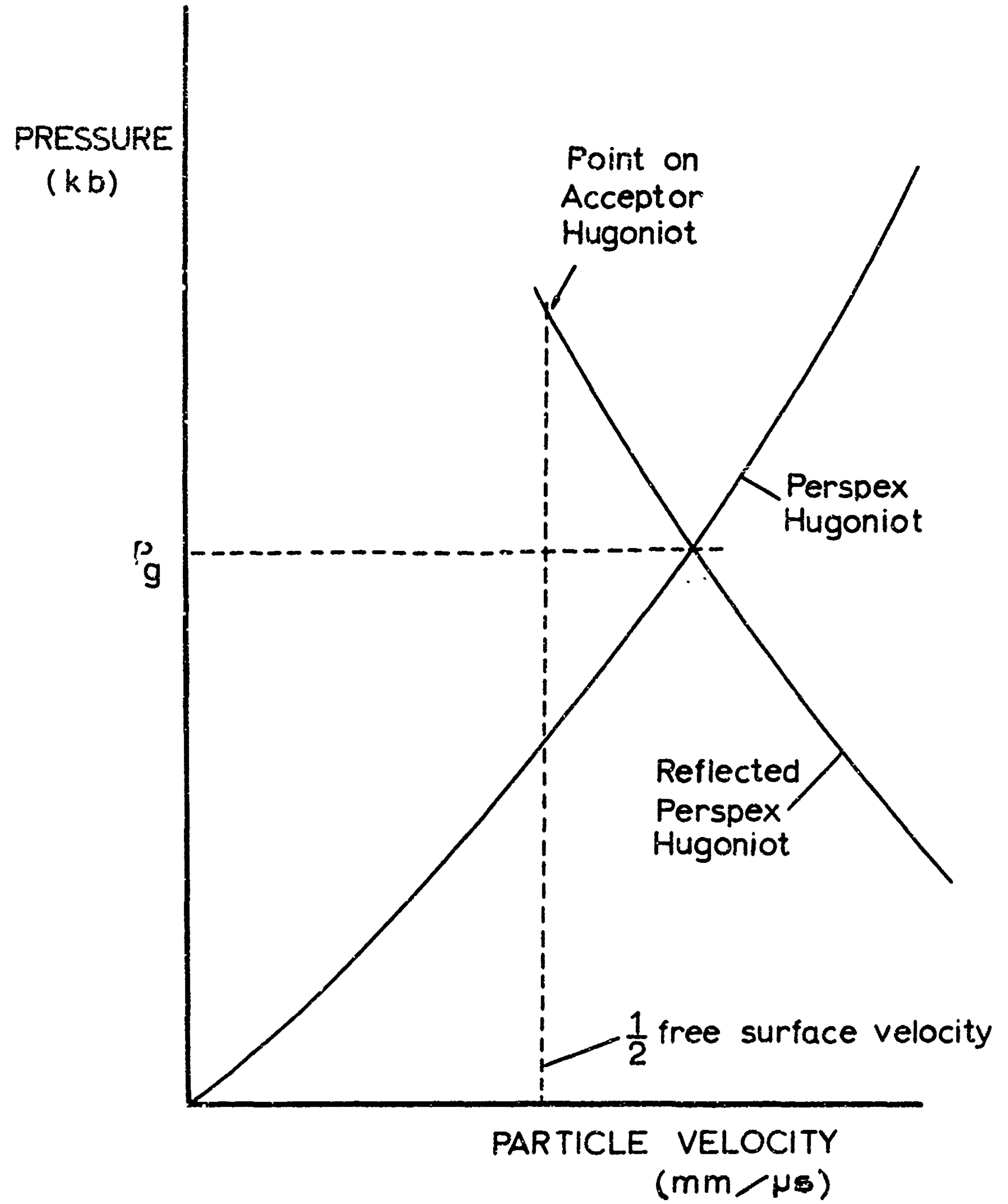

FIGURE 8 Example Acceptor Hugoniot Calculation.

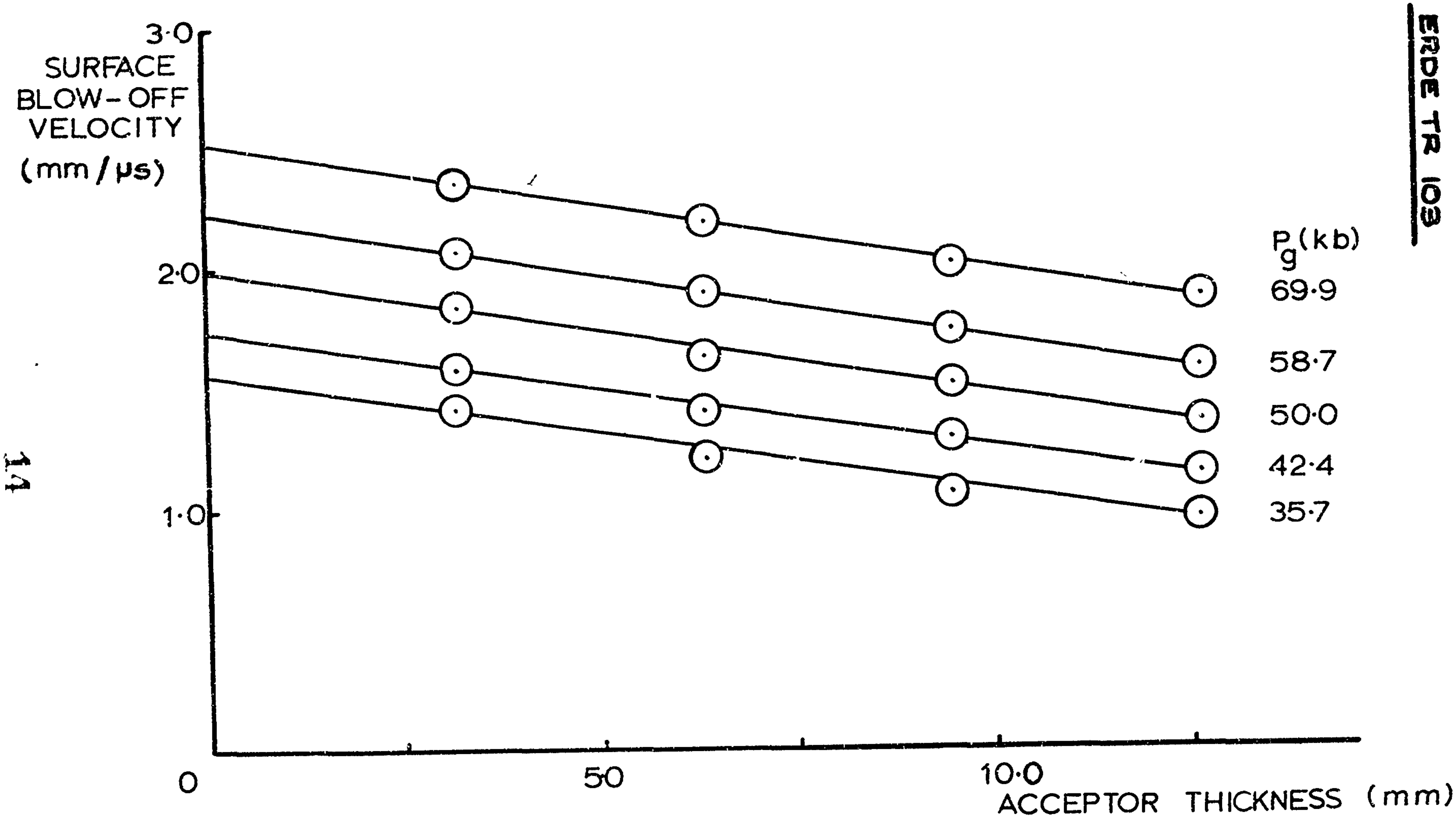

FIGURE 9 Free Surface Velocity Calculations for ATN/D28/47.

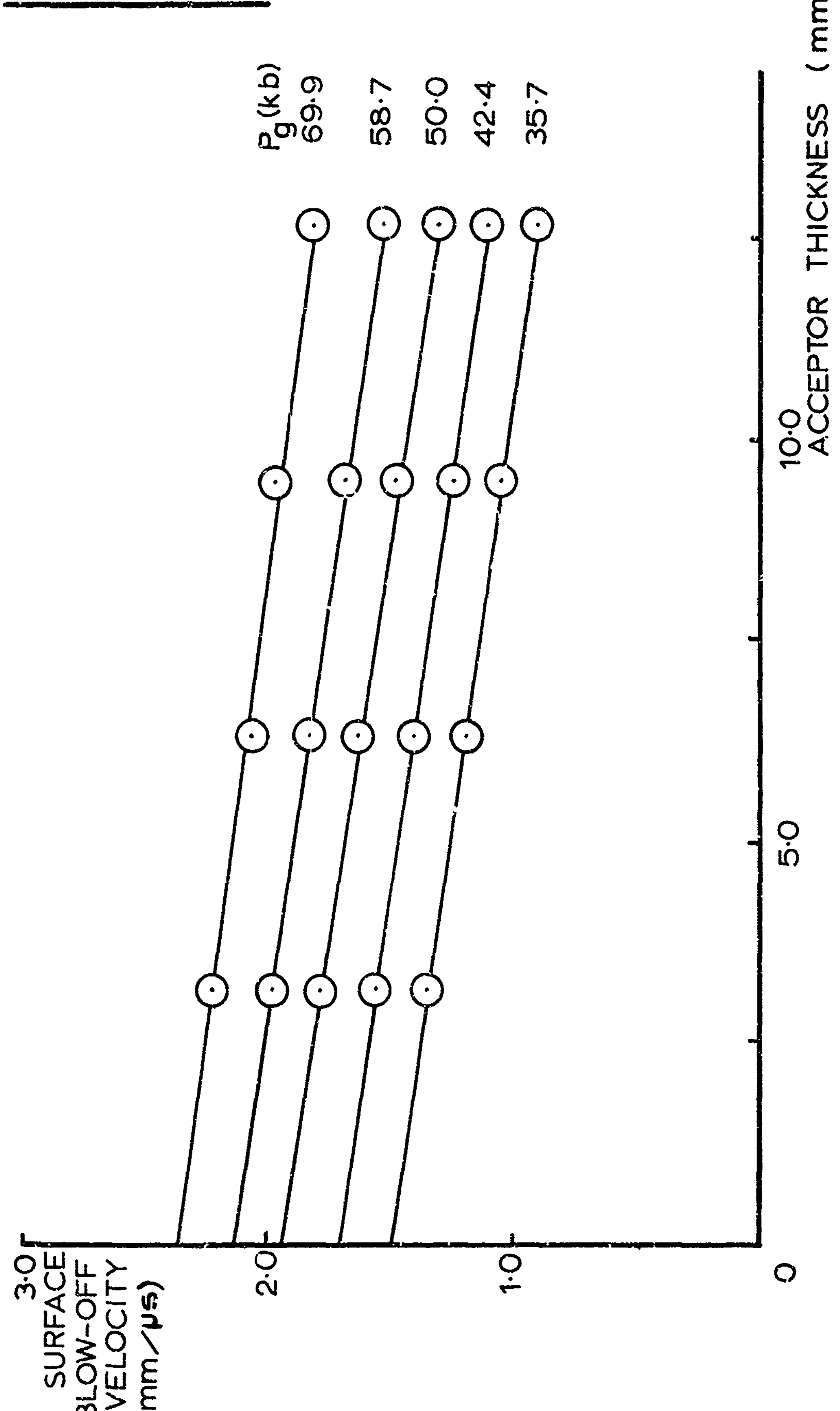

FIGURE 10 Free Surface Velocity Calculations for PU

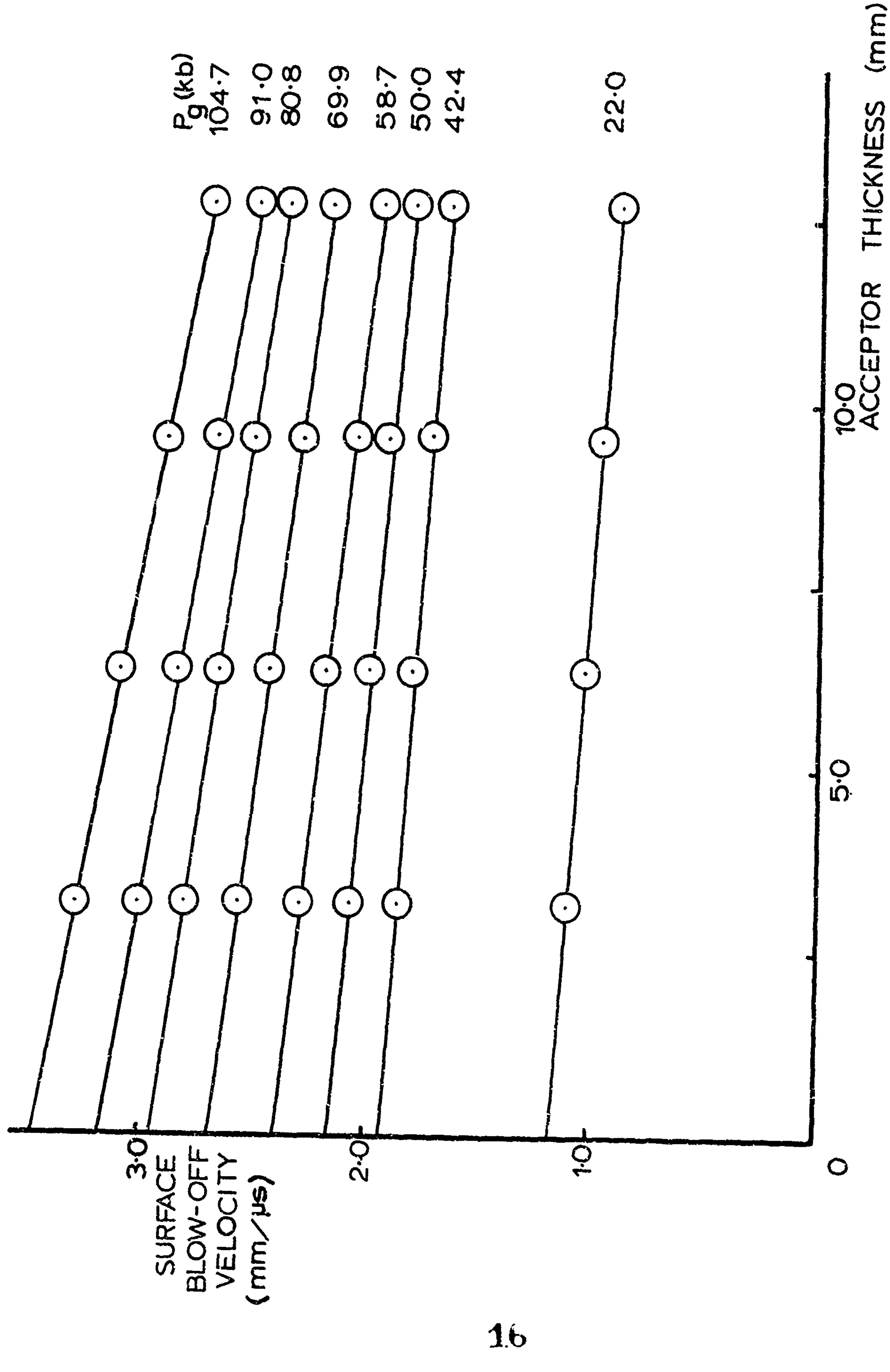

FIGURE 11 Free Surface Velocity Calculations for Nitromethane

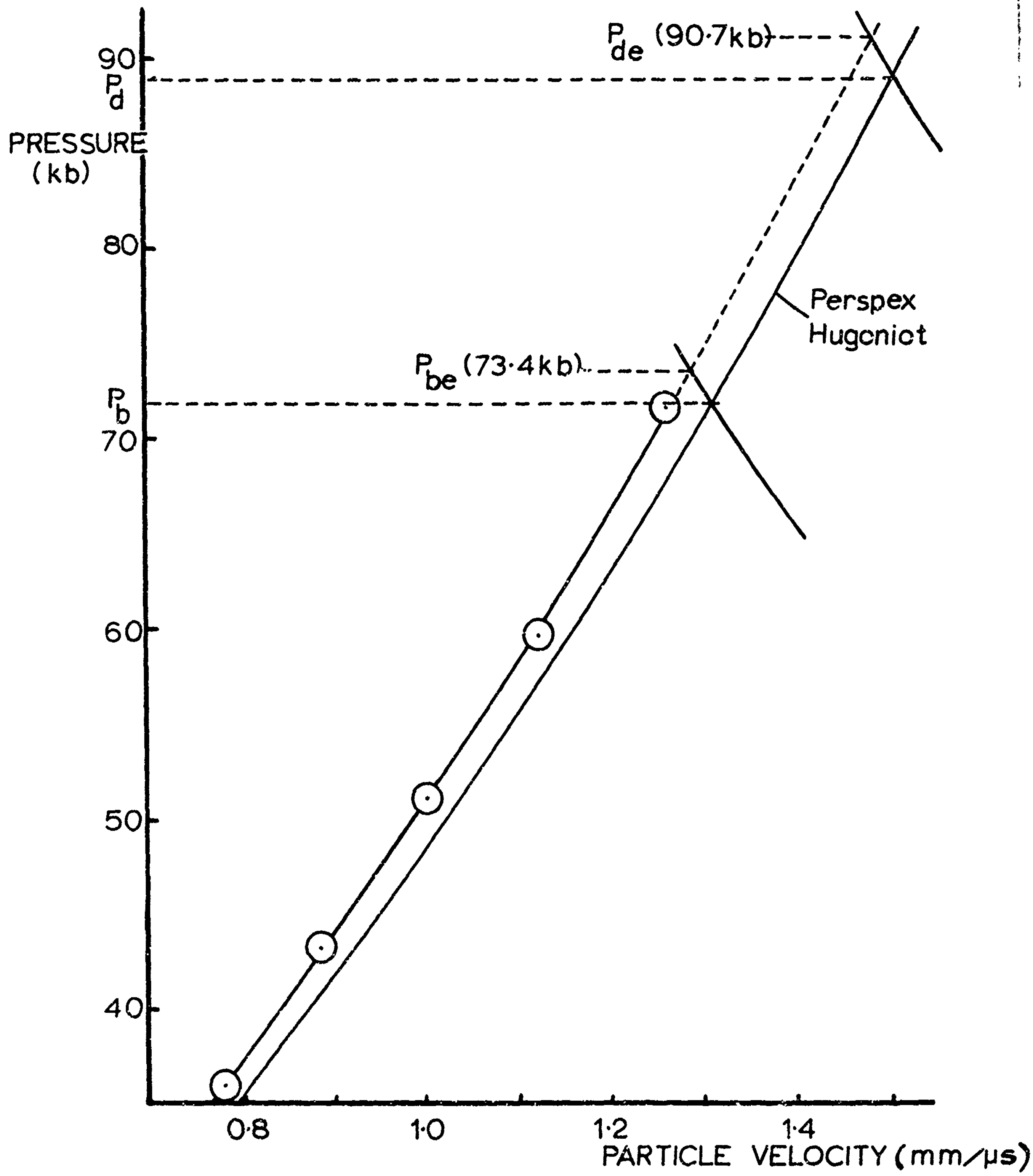

FIGURE 12 P_{be} and P_{de} Calculations for ATN/D28/47

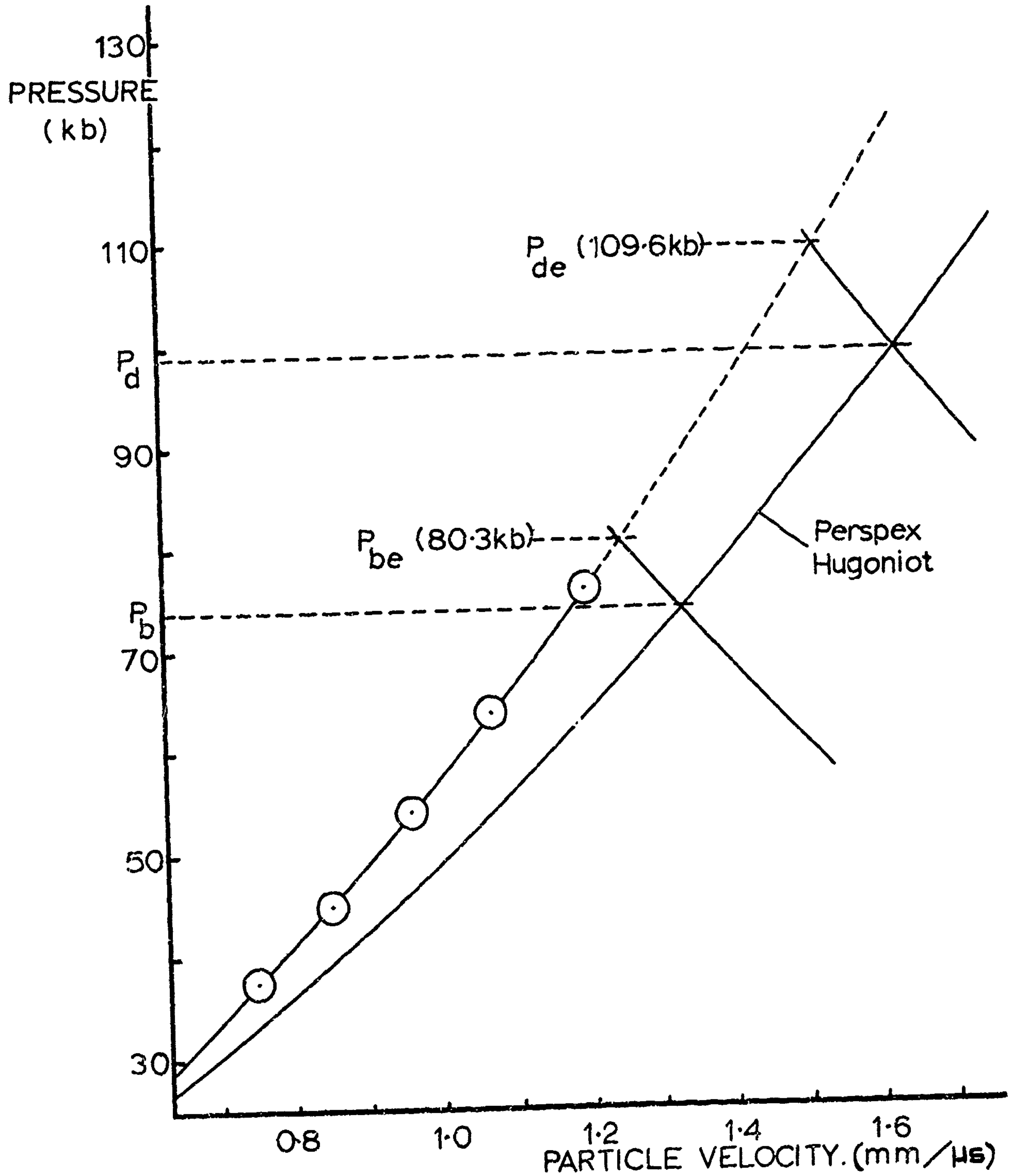

FIGURE 13 P_{be} and P_{de} Calculations for PU

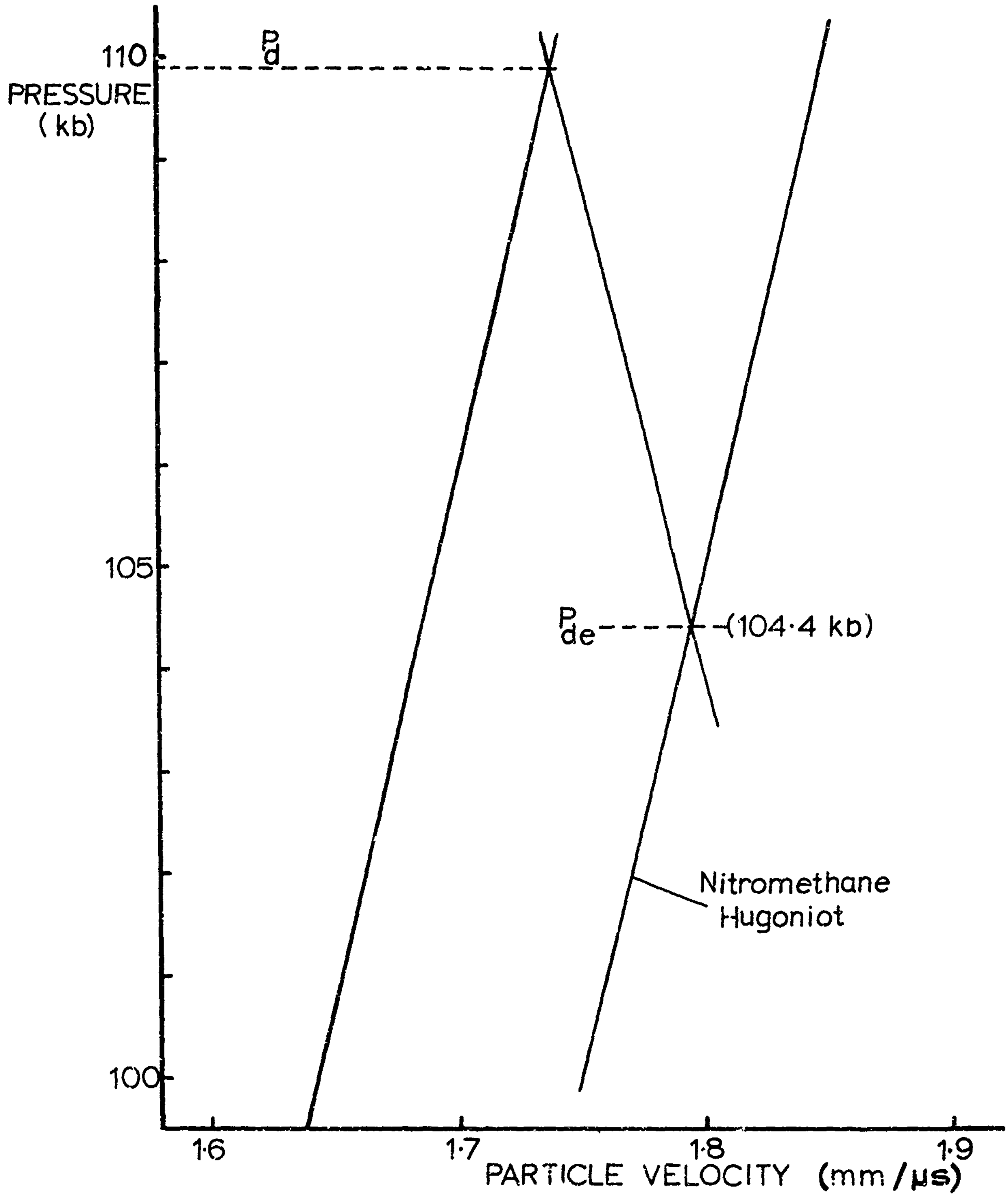

FIGURE 14 P_{de} Calculations for Nitromethane

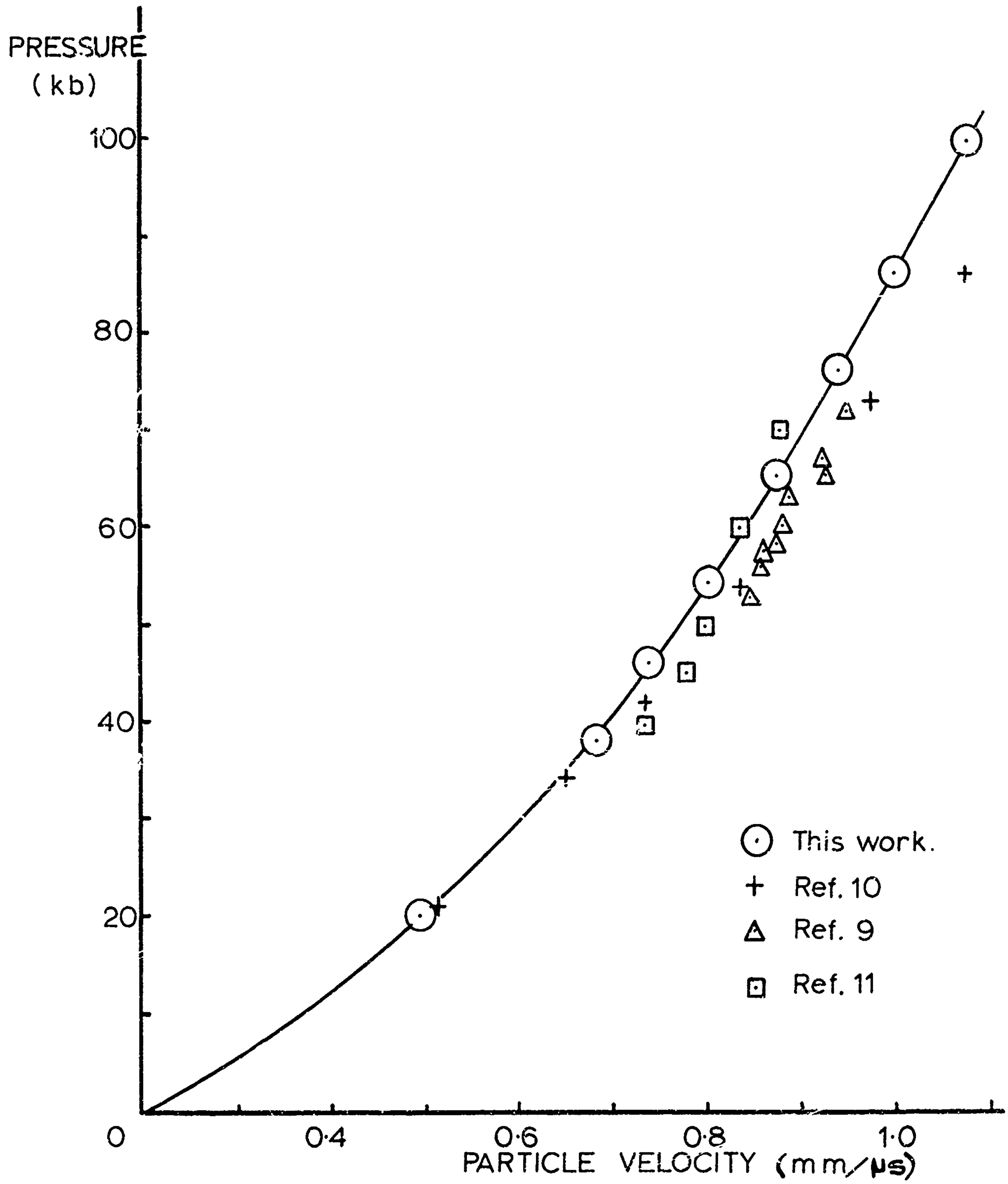

FIGURE 15 Hugoniot Data for Nitromethane